Mechanical Systems and Signal Processing 98 (2018) 936–950

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Relationships between the decoupled and coupled transfer functions: Theoretical studies and experimental validation

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ARTICLE INFO

Article history:
Received 6 September 2016
Received in revised form 9 May 2017
Accepted 13 May 2017

Keywords:
Inverse substructuring
Decoupling
Transfer function
Subsystem
Transfer path analysis

ABSTRACT

A generalized method for predicting the decoupled transfer functions based on in-situ transfer functions is proposed. The method allows predicting the decoupled transfer functions using coupled transfer functions, without disassembling the system. Two ways to derive relationships between the decoupled and coupled transfer functions are presented. Issues related to immeasurability of coupled transfer functions are also discussed. The proposed method is validated by numerical and experimental case studies.

1. Introduction

Noise and vibration in buildings, cars, or airplanes are often the result of the transmission of vibration or structure-borne sound generated by excitation sources. Vibrations generated by the sources propagate throughout the mechanical system or building structure, and are radiated to the air. The noise and vibration characteristics are one of the key factors to make product design successful [1]. So far, a large number of methods have been developed in literature to address these issues, e.g. vibration & noise source identification, transfer path analysis (TPA) and evaluation methods [2–5]. Among these methods, TPA has been a valuable engineering tool for as long as noise and vibrations of products have been of interest [6]. It designates the family of test-based methodologies to study the transmission of mechanical vibrations, and mainly includes the classical TPA: the matrix-inverse and mount-stiffness methods [7], Operational TPA (OPA) [8–10], Operational path analysis with exogenous inputs (OPAX) [11], Component-based TPA [12–14] and Global Transfer Direct Transfer (GTDT) method [15–18]. The family of classical TPA has nowadays become standard practice in the NVH field, since it is a widely implemented and well-known method.

The motivation for the research of this paper is that the classical TPA method, despite having become a well-established and reliable technique for tackling NVH problems, still remains a time consuming and complex procedure [8]. In particular, it requires disassembling the system to measure the decoupled transfer functions. These and related topics make classical TPA still an active research area [16]. In this paper, a method to calculate the decoupled transfer functions based on in-situ transfer functions is proposed to alleviate some measurement difficulties related to the classical TPA. The proposed method can avoid the need of having to remove the active parts of the system when determining the transfer functions. It is indeed peculiar that, despite the fact that classical TPA has been used and developed for decades, such methods have rarely been

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http://dx.doi.org/10.1016/j.ymssp.2017.05.016
0888-3270/

proposed. The most relevant literatures of the research are Refs. [1,9]. In this research a generalized method for calculating the decoupled transfer functions is derived. Issues related to immeasurability of coupled transfer functions are also addressed.

It should be emphasized that the same kind of applications can be found in several earlier publications [19–22], and the related methods are called inverse substructuring methods. The proposed method in this paper can be seen as one member of inverse substructuring methods since decoupled transfer functions are found based on multiple sub-transfer functions of the whole assembly. One will find that the obtained formulas are different from those proposed in these earlier publications. In this research, the proposed method is developed based on the "Source-Path-Receiver" model of TPA, and the links between the active and passive parts are assumed to allow translational vibrations only. To some extent the method proposed in this paper complements current inverse substructuring methods.

Generally, this research provides reliable evidences for in-situ estimation of decoupled frequency response functions. The goals and achievements of this research are as follows:

- To explore the relationships between the decoupled and coupled transfer functions. A generalized methodology to obtain the decoupled transfer function is theoretically derived. An alternative derivation process is also presented.
- To derive a practical methodology that allows the computation of the immeasurable transfer functions based on the known or measurable transfer functions.
- To illustrate the proposed methodology with numerical example.
- To validate the proposed methodology with an experimental case.

The remainder of the paper is organized as follows. The theoretical core of the research is presented in Section 2. It includes the proof of a generalized methodology to compute the decoupled transfer function. The methodology to compute the immeasurable transfer functions is also provided. In Section 3, a numerical example is used to illustrate the theoretical results. The proposed method will be validated in Section 4 through experimental case studies. The article ends with a conclusion in Section 5.

2. Theory

A typical mechanical system is shown in Fig. 1. It is built up from a passive subsystem (part) and an active subsystem (part). These two parts are connected by several resilient mounts. There are three sets of degrees of freedom (DOFs) of interest: Target DOFs, the passive side DOFs and the active side DOFs of the mounts. The coupled transfer functions related to three sets of DOFs are shown in Fig. 2. Usually measurements of the coupled transfer functions performed on the coupled system are easily measured quantities for existing systems.

The coupled transfer function matrix of this system is expressed as

$$\mathbf{H}_{\mathrm{c}} = \begin{bmatrix} \mathbf{H}_{\mathrm{c,tt}}(\omega) & \mathbf{H}_{\mathrm{c,tp}}(\omega) & \mathbf{H}_{\mathrm{c,ta}}(\omega) \\ \mathbf{H}_{\mathrm{c,pt}}(\omega) & \mathbf{H}_{\mathrm{c,pp}}(\omega) & \mathbf{H}_{\mathrm{c,pa}}(\omega) \\ \mathbf{H}_{\mathrm{c,at}}(\omega) & \mathbf{H}_{\mathrm{c,ap}}(\omega) & \mathbf{H}_{\mathrm{c,aa}(\omega)} \end{bmatrix} \tag{1}$$

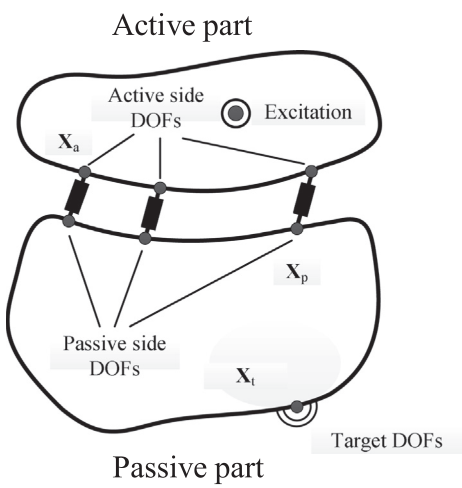

Fig. 1. A coupled system containing a passive subsystem and an active subsystem.